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Proxemics of Screen Mediation: Engagement with reading on screen manifests as diminished variation due to self-control, rather than diminished mean distance from screen

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fidgeting, human-computer interaction, engagement, boredom, proxemics

Abbreviations

EUB - A reading excerpt based on European Union banking regulations
CIDN - A reading excerpt based on the best selling novel the Curious Incident of the Dog in the Night-time
VAS - Visual Analogue Rating Scale

Abstract

Objective: Burgoon's theory of conversational involvement suggest that when people engage with a person, they will move slightly closer to them, often subtly and subconsciously. However, some studies have failed to extend this to human-computer interaction. Our hypothesis is that during online reading, engagement is associated with an expenditure of effort to hold the head upright, still and centrally. **Method**: We presented to 27 participants (ages 21.00 ± 2.89, 15 female) seated in front of 47.5x27 cm monitor two reading stimuli in a counterbalanced order, one (interesting) based on a best selling novel and the other (boring) based on European Union banking regulations. The participants were video-recorded during their reading while they wore reflective motion tracking markers. The markers were video-tracked off-line using Kinovea 0.8. **Results**: Subjective VAS ratings showed that the stimuli elicited the bored and interested states as expected. Video tracking showed that the boring stimulus (compared to the interesting reading) elicited a greater head-to-screen velocity, a greater head-to-screen distance range, a greater head-to-screen distance standard deviation, but not a further away head-to-screen mean distance. **Conclusions**: The more interesting reading led to efforts to control the head to a more central viewing position while suppressing head fidgeting.

Introduction

The Limits of Classical Proxemics

In the mid-20th century a program of research to understand how human communication was a multi-channel signaling system mediated in part by nonverbal, paralinguistic behaviors arose from a confluence of linguistics, anthropology, psychiatry and sociology (Birdwhistell, 1970; Leathers, 1979). An effort was made to annotate and decode these visually observed schemata of events using slow motion films, which resulted in both a wealth of research in anthropology and linguistics (Hall, 1968), and also in the discredited popularized term "body language" (Pease and Pease, 2004). Lay individuals had been known for decades to be able to *decode* (i.e. interpret the social or emotional meaning of) these signals (James, 1932), while experts focused on a program to understand how people naturally *encoded* (i.e. physically emitted) these signals, often outside of their conscious awareness (Mehrabian, 1968). A range of gestures (Kendon, 1983) and facial expressions (Ekman and Friesen, 1971), which arose from observations relating to ethology (Hediger, 1955) and to the foreign service, was ultimately included amongst the nonverbal signals that were being characterized. Based on the slow-motion observation that "human beings are constantly engaged in adjustments to the presence and activities of other human beings" (Birdwhistell, 1970), two key proxemic concepts arose: territoriality (Hediger, 1961; Witchel, 2010) and the zones of interaction (i.e. public, social, personal and intimate (Hall, 1963)). In addition, these nonverbal signals were seen as both the manifestation of personality and psychological states (Burgoon, 2011), as well as implicit messages communicating status, gender, affiliation, deceit and a wealth of other sociological constructs (Mehrabian, 1971).

The precise coding and annotation of nonverbal behavior was divided into the study of proxemics, "the study of how man unconsciously structures micro-space" (Hall, 1955) and kinesics, “the study of body-motion as related to the nonverbal aspects of interpersonal communication” (Birdwhistell, 1952). The goal of this program of research in classical proxemics/kinesics was three-fold: 1) to prove that these nonverbal behaviors did in fact have important communication and sociological functions (Mehrabian, 1971; Leathers, 1979; Burgoon et al., 2011), 2) to categorize those behaviors that were universal to man (Ekman et al., 1969), those that were enculturated (Remland et al., 1995), those that were context dependent, and those that were idiosyncratic but consistent to single individuals, and 3) to list and demonstrate the nonverbal codes (Burgoon et al., 1989). However, the full harvest of utilizing this nonverbal information -- particularly proxemics -- had to wait until computational and sensing technologies could accelerate the analysis of the visual scene beyond the rate of manual coding (Mota and Picard, 2003; Greenberg et al., 2013).

Digital Proxemics

Digital proxemics is defined as, "a digitally inscribed negotiation of personal space through the mutual mediation of actions between space and user" (McArthur, 2016). Digital proxemics has four separate but intertwined research programs:

- RP1. The measurement and interpretation of proxemic information between human beings and digital artifacts
- RP2. The prediction of and reflection on consequences (both benefits and risks) at a personal and societal level of our intimate and proximate relationships with digital technologies
- RP3. The measurement and interpretation of classical human-to-human proxemic information by digital technologies
- RP4. The use by responsive digital technologies of proxemic information to determine modes and/or behaviors of digital artifacts (Greenberg et al., 2013).

The current study is a mixture of research program RP1 and its implications for RP3. In digital interactions, contemporary proxemic measurements encompass seven categories of features: distance, orientation, movement (e.g. speed), identity, location (geographic location and relative position), navigation and wayfinding (Greenberg et al., 2011; McArthur, 2016). Digital measures of proxemics (RP1 and RP3) have two major benefits.

Benefit 1) in ubiquitous computing (ubicomp, (Weiser, 1991; Rogers, 2006)) and responsive systems (e.g. automated tutoring systems, (D'Mello et al., 2008)) they will allow near-effortless interactions (i.e. hands-free, post-WIMP) between people and digital resources (RP4). In the future these proxemic systems may behave so seamlessly that they will border on anticipating a person's needs and desires. In some cases those needs and desires will be explicitly thought by the person but not triggered by their hands, such as in Greenberg et al.'s Proxemic Presenter (a wall-based PowerPoint display) that alters when the presenter approaches the screen (Greenberg et al., 2011) or in devices for disabled people to trigger changes in their environment (Braun and Hamisu, 2009). In other cases the responsive system may seek to detect subconscious or implicit changes in the user's emotion and cognition that are embodied (Mota and Picard, 2003; D'Mello et al., 2008; Ballendat et al., 2010).

Benefit 2) Objective digital measures of proxemics will allow human communication researchers to quantify, reflect upon, and contextualize the validity of the conclusions from classical proxemics (RP3 and RP2); these concern how engagement is encoded as micro-proxemic changes in human-to-human communication. The conclusions from classical proxemics research for human-to-human interactions were often made using subjective assessments (by trained coders (Burgoon et al., 1989)), and even the frame-by-frame manual measurements from classical proxemics counted actions rather than measuring those actions (Bull, 1987); digital measurements will allow for objective quantification of both the number and size of movements. Furthermore, the human-to-human links between proxemics and arousal (Burgoon et al., 1989) may not be the same in some or all human-to-artifact relationships.

Objective Digital Measures in Digital Proxemics

There have been a range of camera technologies that have been used to quantify posture, proxemics/kinesics and emotion. In the 20th century, individual movements (e.g. forward lean or brow/corrugator lowering) were painstakingly manually coded from videos frame-by-frame or second-by-second (Bull, 1987; Coan & Gottman, 2007; Dael et al., 2012), and for certain types of movements and gestures this remains the only reliable method. Also higher level judgments of communication properties (e.g. kinesic/proxemic attentiveness or facial/head animation) have been coded by expert raters based on longer excerpts (e.g. one minute) of video (Burgoon et al., 1989). The micro (or "molecular") assessments have been evaluated against higher/macro level judgments (also called molar level (Burgoon & Baesler, 1991)); while both may be valid, micro level assessments -- although more painstaking to make manually -- are considered preferable for more objective measures.

In the past two decades the profusion of multi-camera opto-electronic motion capture systems has allowed for sub-second and sub-millimeter accuracy during the measurement of proxemics and kinesics (relative position, distance, posture and movement) during human computer interaction (Diaz-Marino & Greenberg, 2010; Greenberg et al., 2011; Witchel et al., 2012). In addition depth cameras (Grafsgaard et al., 2012), which have also been combined with pattern recognition, have been used to derive detailed measurements (Shum et al., 2013). For simple proxemics, a single camera positioned laterally can provide highly accurate information that can be analyzed by video tracking (Witchel et al., 2012; Witchel et al., 2014a; Witchel et al., 2016). In addition, a worn WLAN has been used to determine distance between the wearer and digital objects based on signal strength (Pederson et al., 2011).

There is a major difference between technologies like cameras that measure postural position (essential for distance, relative position and classical proxemics) and those like accelerometers that measure movement (kinesics). As a general rule, one can accurately calculate movement by differentiating position over time; by contrast, if one measures movement, it is usually unreliable to calculate position by mathematically integrating over time (so-called dead reckoning) because small errors in baseline measurement are multiplied. However, accelerometers and other worn inertial motion sensors have an advantage over cameras in that they are not subject to occlusion, so that movement of forearms (which supinate/pronate) and legs (which are often under a desk) can be consistently recorded (Chalkley et al., 2017). There are also technologies for measuring pressure, which give direct measurement of the thigh and back, but do not allow one to derive head position; however, by determining changes over time in these measurements, one can glean postural movements of most major changes in body position including the head. These technologies include pressure sensors in the chair (Mota & Picard, 2003; D'Mello & Graesser, 2014), using the entire seat as a pressure sensor (Seli et al., 2014) and most recently putting sensors in the seat of the user's trousers (Skach et al., 2018).

How Proxemic Information Relates to the User's Cognitive/Emotional States

Approach and withdrawal are the key proxemic responses (Coker and Burgoon, 1987). They occur at a large scale (i.e. approaching and hugging a family member by moving from public to intimate zones), but also moment by moment at a small scale (leaning one centimeter closer to something/someone you want to interact with more (Coker and Burgoon, 1987; Birdwhistell, 1970; Pederson et al, 2011)). Thus, proxemics are thought to be the embodied results of emotions and sociological states (Mehrabian, 1971). Proxemic changes can also cause emotional and cognitive changes (and violations), such as when a Frenchman converses from too close a distance and discomforts an American anthropologist (Hall, 1963). This cycle means that proxemic states are causes, effects, and indicators. The dissemination of this research means that nowadays it is commonly understood, especially in the lay press and folk psychology, that engagement and intimacy are associated with a closeness that is reflected by physical proximity (Pease & Pease, 2004; Sandberg, 2013). This has also been suggested by researchers who measure how people interpret or "decode" the emotional meaning of posture and approach as positive, liking or engagement (Coan & Gottman, 2007; Sanghvi et al., 2011; James, 1932).

However, when researchers rigorously attempted to determine whether people actually "encode" their engagement during seated human computer interaction as approach by measuring second-by-second body positions, they found that engagement does not lead to a noticeably closer average position over time (Mota & Picard, 2003; Witchel et al., 2014b; Witchel et al., 2016). Instead boredom is associated with an increased change in position over time (i.e. kinesic movement or fidgeting), a result that has been replicated repeatedly and accurately with stimuli that are human or digital (Galton, 1885; Bull, 1987; Burgoon et al., 1989; Mota & Picard, 2003; Witchel et al., 2014a; Witchel et al., 2016). There have been many explanations for why fidgeting arises during boredom including mind wandering (Seli et al., 2014; Subhani et al., 2019), an attempt to arouse oneself (Carriere et al., 2013), and that fidgeting is the natural state which is inhibited by self-control during task engagement (Non-Instrumental Movement Inhibition (Witchel et al., 2014a; Witchel et al., 2016)).

Can Digital Proxemics Critique Classical Proxemics?

Digital technologies have revolutionized the potential consequences, as well as the process, of nonverbal communication; for example, interactions between pedestrians and nominally self-driving automobiles involve proxemic interpretation (Rothenbücher et al., 2018). Aspects of these changes have included standardizing interactions toward simplified social conventions that can cope with simplified digital intelligence (Rios-Martinez et al., 2015) onto traditionally nonverbal elements of human experience (Dael et al., 2016).

Proxemics will continue to influence studies of human consciousness because the ways that the brain/mind understands and responds to the self, the outside world, and affordances are highly dependent on spatial distance (Ferri et al., 2013; Perry et al., 2013; Lloyd, 2009). Changing interactive distance is both a cause and an effect of how emotions and cognitions change (Dael et al., 2016), which has led to the measurement of changes in distance during digital/social interactions. This has been traditionally important for assessment of user experience in the design of digital artifacts, particularly as an indicator for engagement (Mota and Picard, 2003; Witchel et al., 2012).

User experience is the subjective relationship between the user and a digital product/activity, and its concerns extend well beyond the actual implementation of the device or application (Calvillo-Gámez et al., 2015; Greenberg et al., 2013; Pederson et al., 2011). As a measurement, assessing user experience has needed to go beyond self-report rating scales for satisfaction and other aspects of user experience (Borsci et al., 2015; Berkman and Karahoca, 2016), to considering how the relationship feels and develops on a moment-to-moment basis, as measured unobtrusively by a range of technologies (Kula et al., 2019).

The Current Study

The research objective in these experiments is to use objective digital measurements to verify how people subconsciously encode their moment-to-moment cognitive engagement and boredom (both measured by visual analogue scale) as micro-proxemic changes (measured by video tracking) when nonverbally interacting with digital monitors. This addresses two issues: 1) how accurate are the subjective measures from classical proxemics (RP3) when measured computationally, and 2) can the cognitive/emotional proxemic encoding rules presumed for human-to-human interactions be generalized to human-to-digital interactions (RP1)? Our aim in these experiments is to revisit and clarify the proxemic response to engagement and boredom during human-computer interaction. We have previously shown that seeing interesting people on the screen (e.g. fun music videos or a montage of smiling faces from the International Affective Photographic System (Lang et al., 2005)) does not result in increased proximity to the screen compared to boring stimuli (Witchel et al., 2014a); however, these experiments were not exactly comparing like-with-like, because it is quite difficult to have visually similar human videos that consistently elicit radically different emotions. Here we use two directly comparable text stimuli, both of which involve reading from a screen combined with a clicking task that forces screen engagement; one of the readings is interesting (the opening from the best selling novel the Curious Incident of the Dog in the Night-time by Mark Haddon (CIDN)), and the other reading is an equivalent length of European Union Banking regulations (EUB), which most people in our experiments found quite boring.

We are testing two theories that potentially suggest different outcomes:

A) Approach is embodied engagement (e.g., Coken & Burgoon, 1987; Coan & Gottman, 2007) vs.

B) Non-Instrumental Movement Inhibition (NIMI) is the primary response to cognitive-only visual engagement (Witchel et al., 2014a).

Our hypothesis is that (H1) boredom is associated with extensive head movement due to restlessness and (H2) cognitive engagement is associated with an expenditure of effort to hold the head upright, still and centrally (as opposed to being as close as possible to the monitor). It has been previously shown that engagement is associated with stillness (Witchel et al., 2016; Bianchi-Berthouze, 2013), and in the current experiments we are seeking to support the idea that the head position is central compared to where the head may move. We propose a reason why the lay belief that computer engagement leads to approach has usually not been replicated in controlled digital measurements of the average distance between the monitor screen and an end-user's head. We propose that there are many situations of extreme boredom that lead to approaching the screen, such as resting the head on the hand (Grafsgaard et al., 2013) or even resting the head on the desk (Witchel et al., 2014a). When these boredom-approach events are mixed with seated disengagement that manifests as leaning back and slouching, the combination confounds simple linear calculations to show that interest leads to net approach.

Methods

Participants and Procedures

Participants and ethics. Twenty-seven participants (mean age 21.00, SD = 2.89, 12 male) were recruited via email from the university community at a pair of universities in the south of England for an experiment lasting about one hour. Ethical permission was granted by our local institutional ethics board (BSMS RGEC) before commencing these experiments. All participant interactions were guided by the Declaration of Helsinki, with informed consent and the ability to withdraw at any time being stressed. The participants received £20 for their travel and time.

Stimuli. The reading stimuli used during these experiments have been described previously (Witchel et al., 2016). In brief, ~800-word-long excerpts were derived from the Curious Incident of the Dog in the Night-time (Haddon, 2003) and from European Banking regulations (European Banking Authority, 2013). These experiments were run at least one year before the Brexit vote, when the European Union was still viewed as boring rather than as a political issue or a threat. The excerpts were presented using Flash 8, and the readings were scrolled up the screen like movie credits at a slow rate (24.4 lines per minute). There were 50 characters per line, allowing for approximately 4 words per second. The screen size of the monitor was 47.5 x 27 cm and the height of the lettering was 6 mm tall for capital letters and 4.5 mm tall for lowercase letters (14 point Verdana bold in Flash's design mode). For an average eye to screen distance of 72 cm, this creates an arc of 0.477 degrees for capital letters and 0.318 degrees for lower case letters.

Presentation to participants. Stimuli were presented with the participants alone in the experimental room. To vouchsafe that they persisted in reading, two aspects of the tasks were specially designed to prevent undetected disengagement. The tasks were presented to the participants as reading comprehension tasks, and at the end of each reading stimulus, the participants were asked a true/false questions about the contents of the excerpt. The movements of the participant during the test part of the task were not included in the results of these experiments. In addition, to guarantee that the participants were paying attention on a moment by moment basis, they were given a concurrent clicking task. Approximately every two seconds the screen became uniformly gray (so that it was impossible to see any of the reading text) except for a message that said, "Click anywhere to continue reading". The click points were pseudo-randomly distributed, and appeared at the same times on both reading tasks. The click times were recorded so that it was possible to detect individuals who were not paying any attention; no such inattentive participants were found.

Measures

Subjective measures. Subjective measurements were made immediately after each video. These began with an open text question asking the participant for one or two words/phrases to describe, "While you were watching the previous stimulus, what did you feel?" This was followed by a series of ratings scales using a 10-cm Visual Analogue Scale (VAS), with ratings from 0 (anchor = "not at all") to 100 (anchor = "extremely"). In this study we consider only the descriptor, "I felt boredom".

Manipulation Check: Subjective Responses to Stimuli. As per the design of the stimuli, we expected participants to be interested in the reading excerpt based on the best selling novel (CIDN) and to be bored by the European banking regulations (EUB). The subjective ratings we gathered fit strongly with our expectations (Figure 01), although not every single participant provided exactly those ratings. Note that the mean subjective rating for boredom (black horizontal lines) show that EUB was more boring overall, and that almost all individuals (lines) rated EUB as being more boring than CIDN (dark blue lines diagonally down and right) while only two individuals rated the novel CIDN as more boring (red lines up and right). The mean rating (on a 0-100 scale) for "I felt bored" after EUB was 68.77 ± 32.49 (mean ± SD) compared to a mean rating for CIDN of 22.88 ± 22.01 (N = 27). This difference in values had an effect size of 1.65 (Cohen's d) and resulted in a P value of 8.8×10^{-5} (Wilcoxon Signed Rank test). This proves that the reading excerpt from the best selling novel was much less boring than the EU banking regulations, as we predicted.

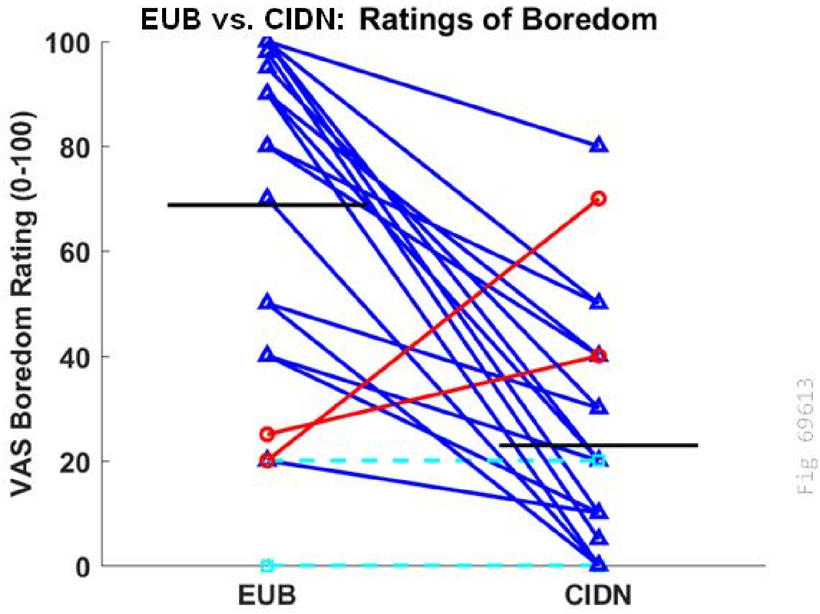

Figure 01. Post-stimulus Visual Analogue Scale ratings of boredom for EUB and CIDN. The black horizontal lines are the group means. Each colored line represents the paired data from a single participant, where red are those participants whose ratings for CIDN were greater than for EUB, while dark blue is when the rating during EUB is higher than CIDN, and cyan (dashed) are when the ratings were the same in EUB and CIDN..

Video analysis and statistical analysis. Behavioral measurements were based on video tracking from a single lateral video camera. Distance/position was the calibrated x-position (horizontal) of the body part (recognized with a motion-tracking marker) minus the x-position of the fiducial point on the user's monitor. Speed was the absolute value of the sample by sample differences in x-position divided by the difference in elapsed time. The participants had six reflective motion tracking markers placed on them at the beginning of the experiment, all on the left side of their body facing the camera: outer canthus of the eye, pinna of the ear, badge of the shoulder, greater trochanter of the thigh, middle of the thigh, and 2 cm below the head of the fibula. In this particular manuscript, only the head movements are being reported. The movements of all the markers were recorded by a video (25 Hz) from the lateral aspect (see Figure 04 A for an example of what was recorded by the camera (Canon MV 890), including the positions of the tracking markers). The markers in these videos were tracked (i.e., as x-y coordinates for each frame) by Kinovea 0.8 (www.kinovea.org). The data outputted from Kinovea (in xml format) were analyzed in Matlab, including calibration as described previously (Witchel et al., 2014a). These measurements have been previously shown to almost exactly reflect the measurements made with the gold-standard Vicon system (Witchel et al., 2012). Non-parametric statistical tests were performed in Matlab; whenever the data was paired, the Wilcoxon Signed Rank test was used.

Results

Representative Proxemics Data: Head Distance from the Monitor Screen

Data that is representative is shown to demonstrate the derivation of the group data, and to clarify the methodology quality when gathering data. The distribution for the moment-by-moment measurement of head-to-screen horizontal distance shows how the distance between the forehead and the monitor varies over time around a central point (Figure 02 A). For this participant, who was fidgeting extensively when bored (each variation of the time course graph that moves away from a flat horizontal line is a fidget), the mean from the forehead marker to the monitor over the entire course of the 185 second EUB (boring) stimulus was 56.10 ± 0.84 cm (mean ± SD). The head's distance to the monitor during the EUB stimulus covers a range of values (from approximately 53 to 59, range = 5.83 cm). Panel B shows a histogram summarizing the distribution.

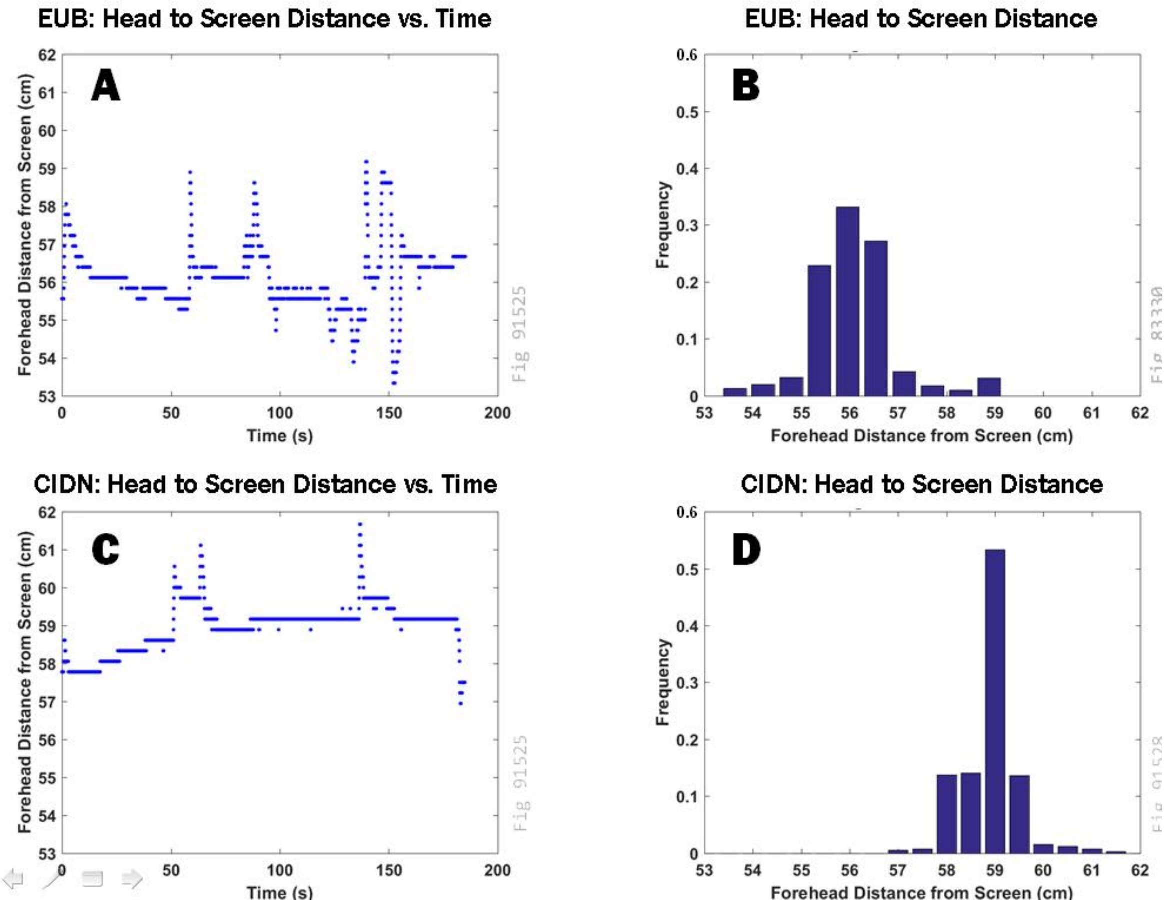

Figure 02. Representative data of the head-to-screen horizontal distance during the boring EUB stimulus vs. the interesting CIDN stimulus for participant Y075. Panels A and C show the time course data, while B and D show the distribution of the data.

The same participant's proximity to the screen during the CIDN (interesting) stimulus is shown in panel C (which should be compared to panel A, which is more variable and lower on average). Again, the forehead position varies around a central point (58.98 ± 0.63 cm). As with the other stimulus, the distance to the monitor covers a range of values (from approximately 57 to 62, range = 4.72 cm). While this range is similar to the range covered during the EUB stimulus, it is noticeable that the frequency of large changes (spikes) is much larger in panel A (when bored) than in panel C. This represents fidgeting as would be detectable as a change in head speed (i.e. absolute velocity, see (Witchel et al., 2016)). The distribution of the CIDN data is shown in panel D. When comparing the two distributions panels B and D), there is fairly little overlap between them on the horizontal axis, and the participant's head was on average closer to the screen during the boring (EUB) stimulus (Panel B) than during the interesting stimulus (Panel D). Also the distribution of head positions is more compressed during the interesting stimulus (width of distribution in panel D) than when bored (panel B).

Another set of representative data for the same two stimuli but a different participant are shown in Figure 03. This is shown because during the boring EUB stimulus this participant suddenly positioned her head close to the monitor during the final 30 seconds of the boring EUB stimulus (panel A, time = 150-180 seconds). Panel B shows that this change in head position resulted in a bimodal distribution of head positions, with peaks at 48 cm and 64 cm. The change between these two positions occurred rapidly (over a 5 second period, see Figure 04) and probably represents a compliant act to forestall boredom (Carriere et al., 2013). In the open text response, this participant described her emotions during this task as "frustrated and stressed", and her VAS ratings (out of 100) for "I felt interested" was 0, she rated "I was totally engaged by the experience" as 20, and "I felt bored" as 90. In the video the participant can be seen moving her lips while reading at the time she was sitting forward.

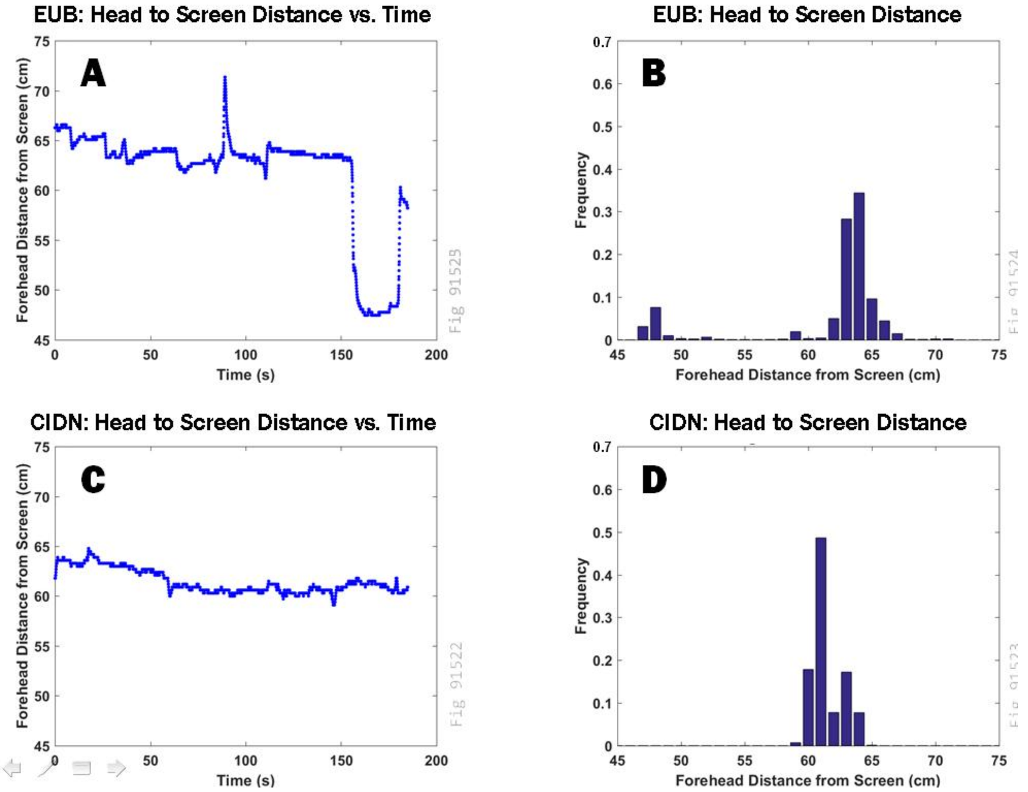

Figure 03. Representative data of the head-to-monitor horizontal distance for a volunteer (Y072) who leaned forward for part of the EUB stimulus.

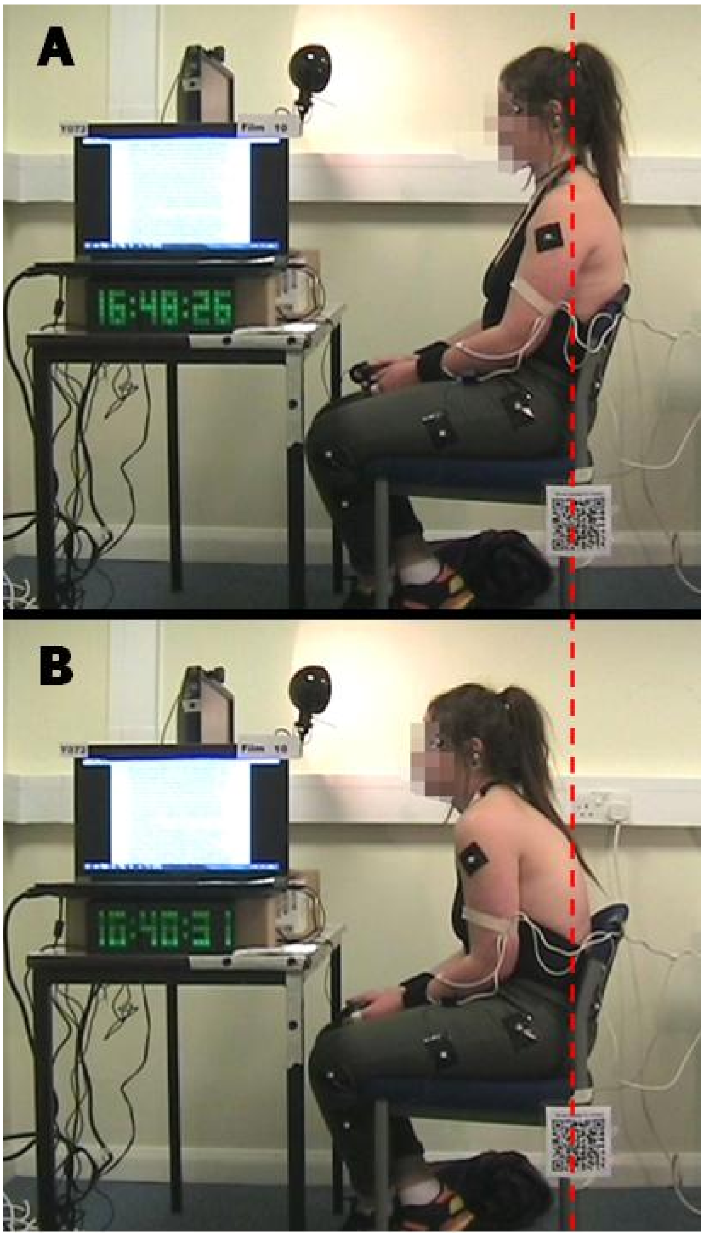

Figure 04. Anonymized frames of a participant just before (A) and after (B) she leaned forward 15 cm while reading the boring EUB stimulus. This action occurred toward the end of the stimulus (after 150 seconds). Red dashed line added for comparison.

Key Result: Mean Distance from the Monitor

The mean horizontal distance of the forehead marker from the monitor during these two stimuli were not statistically different according to a Wilcoxon signed rank test ($P = 0.5642$, where $N = 27$ for this and all following calculations). As can be seen in Figure 05, the group means for each participant's mean distance from the forehead to the screen barely differ (black horizontal lines are at the same level, differing by only 7 mm, for EUB versus CIDN the distances were 72.89 ± 8.93 versus 72.14 ± 7.28, mean ± SD). However, the lack of difference in the group means represents a lack of a consistent difference (note the near equal number of blue (14) and red (13) diagonal lines) rather than a similarity (which would have resulted in many horizontally flat lines). The absolute values for the difference in the forehead position for the two stimuli were on average 2.28 ± 2.63 cm apart. This implies that there is not a precise (i.e. < 2 cm) viewing distance that the person's head returns to for each reading. The horizontal position for the shoulder marker also lacked any consistent pattern. The mean values for shoulder distance were 82.48 ± 9.66 versus 82.13 ± 8.64 (P = 0.7548, Wilcoxon sign rank test), and the absolute values for the difference in the shoulder position for the two stimuli were on average 1.15 ± 0.95 cm apart horizontally.

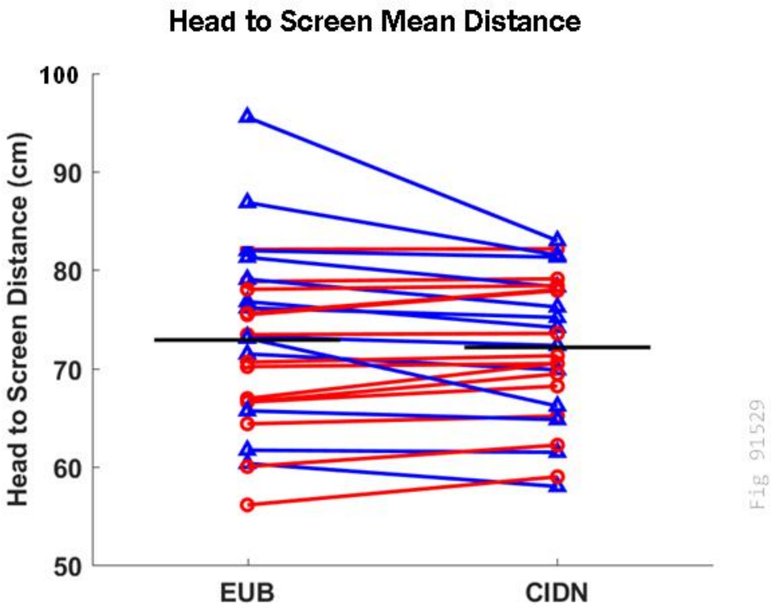

Figure 05. Mean of the head-to-screen distance computed over the duration of the stimulus time course.

Standard Deviations and Ranges of the Distance from the Monitor

For each person-stimulus time course we computed the standard deviation to determine whether the distribution of head positions and their variation were consistently different between the two stimuli. Figure 06 (black horizontal lines) shows that as predicted, the standard deviation during the interesting CIDN stimulus (group mean of the individual time course standard deviations = 0.83 ± 0.46) showed a trend for being less than the standard deviation during the boring EUB stimulus (1.19 ± 1.00 cm, P = 0.058, Wilcoxon Signed Rank, Cohen's d = 0.469). The difference in variation between the two stimuli was even more apparent when considering the range of head positions (i.e. the difference between the two extremities of the head's movement, Figure 07, black horizontal lines). During EUB the group mean for each participant's head's range was 8.11 ± 5.97 cm, while the mean of the ranges during CIDN was 5.40 ± 4.37 cm (P = 0.0271, Wilcoxon signed rank test, Cohen's d = 0.518). Note how the number of blue lines (19) far outnumbers the number of red lines (8).

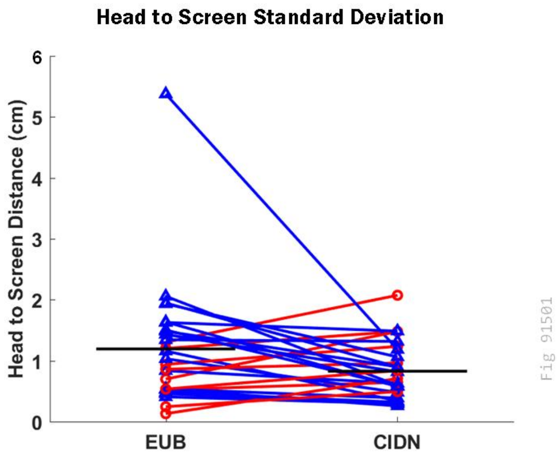

Figure 06. Standard deviations for the individual time courses of the head-to-screen distance during the two stimuli.

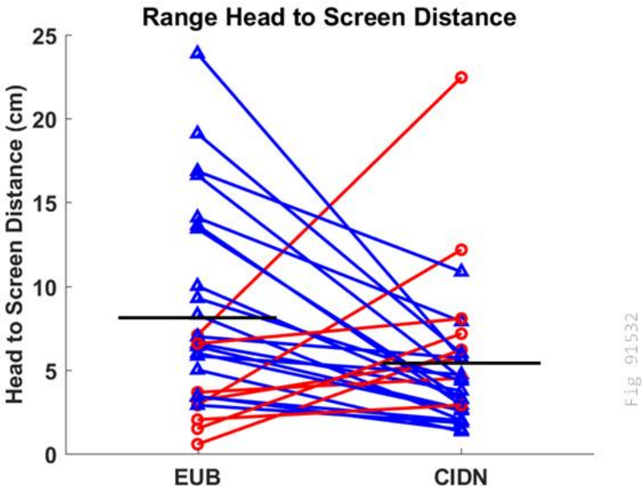

Figure 07. Ranges for the individual time course of the head-to-screen distance during the two stimuli.

Discussion

Researchers in classical proxemics (Galton, 1885; Bull, 1987; Coker and Burgoon, 1987; Coan & Gottman, 2007) and digital proxemics (Sanghvi et al., 2011; Rodrigo & Baker, 2011) have long worked with the understanding that human engagement/involvement in communication with another person or object is encoded, moment by moment, by approach or withdrawal according to their interest in the other. However, this result often failed to be reproduced during computer interactions, when it should have manifested as a net diminution in time-averaged distance during continuous objective digital measurements (Mota & Picard, 2003; Witchel et al., 2016). In this study we used objective digital video tracking to analyze the time course of horizontal distance between the forehead of a seated human user and the monitor screen of a computer during two very similar reading tasks (one interesting, one boring) that force screen engagement through regular responsive demands, and which we have established produce stable and reliable subjective responses. We found four relevant results during these short tasks using these measurement techniques:

- The head-to-screen distance tended toward a central value, with short excursions toward and away from the screen (H2 is correct).
- The central value of the head-to-screen distances was not a constant (within 2 cm) between stimuli, and the central value was not obviously dependent on interest.
- However, the variation of head positions was greater during boredom than during interest, and this was reflected as a greater range and standard deviation of head-to-screen distances during a 3-minute time course (H1 is correct).
- These data also reproduced previous results showing that the speed of head movement (in the horizontal plane) was faster in the bored state.

These results indicate that classical micro-proxemics *per se*, i.e. as a measure of absolute distance between the subject and the object of their attention, do not reflect degree of interest, at least in the case of on screen reading. Measuring the amount of variation in head position from the center, which we might term the optimum head-to-screen position, does produce indicative metrics of interest, however. When bored, head movements in relation to the screen vary more in range (distance to the screen), whereas participants are more consistently positioned near their central position when interested. To some extent the central tendency may relate to shoulder position. In addition to proposing this metric as a form of relative or contextual proxemics indicating interest during seated screen engagement, we may conclude from these results that during any 3-minute period there is an optimum head-to-screen position, and that this position is related to unknown factors that likely include shoulder position, seat and seat back position, as well as optimal reading distance from the screen.

The range of head-to-screen distance has good discriminatory ability for boring versus interested states. We would caution against its usefulness as a metric of interest during extended screen engagement, however. While it works well for the viewing conditions in these experiments (3-minute-long, homogeneous stimuli), there is a greater likelihood that the head may move to an extreme position by chance or for reasons other than boredom as time passes. The feature of mathematical range concerns the most extreme positions; thus, for a seated person over time, range must perforce reach a ceiling effect, and it is not a measure that is robust to sudden unexplained outlier movements.

Potential Implications to Digital Proxemics

The fact that the head-to-screen distance is not consistently closer during pleasurable or interesting reading (compared with boring and disengaging reading) suggests that liking or cognitive engagement *per se* either A) does not directly mediate micro-proxemic approach to screen engagement, or B) has a very weak effect on proxemic approach that is over-shadowed by other effects on approach. The difference in mean position between the two reading tasks could be as large as 2 cm in the same person, and was inconsistent with the degree of interest. This suggests that optimal reading distance varies over time, as well as between people, making time-averaged distance an unreliable indicator of interest when reading on screens. Similar results were found during experiments with video (non-reading) (Witchel et al., 2013) and video game tasks (Mota and Picard, 2003), where interest/engagement also did not lead to a reduction in head-to-screen distance.

In a Situated Space Model (SSM, Pederson et al., 2011), the virtual space around the user is described ego-centrically as items (from furthest to closest) inside the world space, the perception space, the action space, the recognition set, the examinable set, the selected set, and the manipulated set. In such a model, items that are more relevant to the user's perceived affordances and actions (Norman, 2008; Gibson, 1977) are temporarily more central in the SSM, and are typically closer to the user in physical or virtual space. Based on previous investigations of engagement, cognitive and physical engagement must be distinguished (Kahn, 1990; Witchel et al., 2016), because they result in different effects upon the user. Consider Greenberg et al.'s Proxemic Media Player (2011), which changes its behavior mode depending on the proxemic information about nearby users it receives from automated measurements from the Proximity Toolkit. When the user is most cognitively immersed (rapt engagement in Witchel's terminology (2014b)), they are sitting at reasonable distance while watching a video. By contrast, when the user is interacting with the Proxemic Media Player's affordances (when selecting a video), the physical engagement brings the user right next to the monitor. This approach is associated with the Proxemic Media Player making each possible video much smaller. In essence, the greatest cognitive engagement (and immersion) occurs within the recognizable set, outside the range of the examinable set and of the selected set.

In the example of the Proxemic Presenter (Wang, see Greenberg et al., 2011), which changes PowerPoint's working mode based on the proximity of the presenter to the screen, the speaker would be most cognitively engaged in the flow of the talk when oriented toward the audience (i.e., facing away from the screen) and standing far away from the screen; in this situation the Proxemic Presenter shows only the audience version of the talk. By contrast, when the speaker has forgotten his train of thought (and is most needy and least cognitively engaged in his own presentation), the speaker approaches the corner of the screen, and the Proxemic Presenter displays a subscreen of speaker notes that only the speaker can see. Furthermore, when the speaker needs to flip through their slides (an event that usually frustrates and disengages audiences), the speaker turns his back to the audience, approaches the center of the screen, and the Proxemic Present shows a scrollable deck of slide thumbnails. Again in this example, cognitive engagement with the media (and its ideas) is associated with a medium distance from the screen, while approaching the screen is associated with exercising affordances and increasing physical engagement, but at the expense of engagement with the represented ideas.

One possible interpretation is that approach is connected with affordances based on the peri-personal space (Lloyd, 2009). While intimate interaction may include actions that require closeness, this is not the case with ideas or stories on a computer screens. A non-touch computer screen is definitely "an external object"; it is not a tool that might function as an extension of your body, or a person with whom you exchange touch. Since there is no affordance or action that requires propinquity with a non-touch screen - only visual gaze and recognition – there is no rationale (subconscious or otherwise) for proximity as an expression of liking or appeal.

By contrast, the centrality of the head-to-screen position during these experiments' reading tasks, and the reduced variability (both in terms of range and standard deviation) imply that liking is associated with greater control of the head's position, and thus more motivation to suppress task-unrelated postural adjustments (NIMI; see below). This complements previous results showing that boredom increases velocity and reduces control or suppression of task-unrelated movements, which implies that boredom either creates or enables a relatively forceful impetus to move. These potential changes -- in relative velocity or in control of the head and limbs -- are analogous to observations from gait, where increased gait velocity reflects force or motivation to move, while decreased gait variability represents better control (Allali et al., 2017). In the bored state, the increased velocity may be a product of restlessness, which is the active form of boredom (while lethargy is the physically passive form of boredom (Witchel et al., 2014b)). Previous research has demonstrated that cognitive engagement is related to non-instrumental movement inhibition (NIMI, Witchel et al., 2014a; Witchel et al., 2016), which also describes the decrease we see in head velocity in these experiments. In the current study we show that the range and velocity of movement is larger during boredom, with less control and reduced orientation towards a central position of the head. This shows that restless movement is not only more frequent, but that the fidgeting associated with boredom strays widely and is relevant across a variety of experimental conditions.

These experiments have extended the possible metrics of body movement that can be used to discriminate boredom from interest and which contributes to different dimensions of NIMI. These include range (Figure 07, although this has theoretical limitations in longer durations, see above), the standard deviation of 2-second ranges (Witchel et al., 2014b), the velocity of the head (Witchel et al., 2016), and in the study discussed here we have shown that the standard deviation of position will also be valuable (Figure 06). We have previously shown that there is increased movement in the head, shoulders and thighs during boredom and/or disaffection. Relevant to proxemics is the refinement of the idea of distance during screen interaction. This distance, between the central or optimal vantage point for viewing the screen and the outer range of head movements extending radially from this point, is dynamic. In support of this argument, although beyond the scope of proxemics and thus of this paper, it has been established in earlier studies that thigh movement is the most potentially useful metric for assessing an individual's boredom as the background movement is so low (Witchel et al., 2016).

Posture: Limitations of Experiments and Effects of Computer Use

These experiments were performed with reading excerpts used as stimuli. RP1 would ideally test the relationship between humans and digital artifacts, and compare this to the relationship between humans and other humans (or live humans on a screen). Reeves and Nass (1996) have presented a range of evidence (e.g., people using politeness with laptops) to provocatively suggest that people relate to digital artifacts "as if" they were other people. However, the content and media presentation of the media artifact (i.e. whether the screen shows a person or text, and whether that person is recorded or is directly responding to the user) will assuredly make a difference. Our initial measurements comparing speed dating to HCI shows that people move at least three-fold more when interacting with a live human during a speed date than when interacting with a computer (Witchel et al., 2019).

These experiments were performed with a viewing regime similar to a desktop computer (i.e. without a touch-screen). One major difference between our experimental set up and a workplace desktop computer is that the middle of our experimental monitor was adjusted to the eye height of the participant; in a traditional work environment the center of the monitor would be lower than eye height, such that the angle from eye to screen would be at 24 to 29 degrees downward, where 0 is the horizontal (Kroemer and Hill, 1986). Thus, our set up was not that of a traditional office, but it did have the advantage that fatigue (leading to forward head pitch) would not be a confounder in our results (see below).

One mechanism by which digital proxemics may affect the body and its movements is via repeated use (McArthur, 2016). Habitual computer use may lead to altered hand and wrist positions (Young et al., 2013), repetitive strain injuries (Keller et al., 1998) as well as to poor habitual posture (Straker et al., 2007; Young et al., 2012). While the mechanism to poor posture may be via forward lean (i.e. pelvic forward tilt) that is compensated by hyperlordosis, which is seen in female habitual computer users, males are more likely to have increased head and neck flexion. This gender difference may be mediated by the difference in heights in males versus females (Straker et al., 2007) due to a confluence of ergonomic causes:

- The preferred line of sight angle during seated work is -29 degrees below the horizontal (Kroemer and Hill, 1986)
- as a result, the standard work position of computer monitors is slightly below the horizontal, making the centre of the monitor lower than eye height (Burgess-Limerick et al., 1999)
- computer workstations are often not adjusted for height of the individual (Laeser et al., 1998), and
- thus, to allow for the gaze to be at the centre of the computer monitor, the parameter "standing height" affects neck flexion during seated computer use (Briggs et al., 2004),
- the greater height of males will lead to greater neck flexion, while the lower height of females will lead to pelvic forward tilt and hyperlordosis.

To prevent these issues from affecting our experiments, we explicitly adjust the height of the centre of the monitor to be level with the participant's eyes, and we also use a handheld trackball that prevents the need to bear the arm weight on the carpal area (see Figure 04).

Conclusions

When seated digital-to-human communication is interpreted according to Burgoon's theory of involvement, cognitive engagement and mean proximity are not directly associated at a subconscious level. These experiments have shown that *the distribution* of the head-to-screen distance (e.g. the range and the standard deviation) reflect boredom when seated and reading from a screen. Future research of screen distance needs to establish whether liking or engaging with a screen-mediated "live" and responsive person causes the user to approach the screen, as the movement patterns and perhaps also proxemics in relation to interaction with an on-screen live person will be a different from reading or watching a movie/video. In fact, an entire research program based on different types of stimuli (with and without people, with and without liking, with and without possible interaction) could and should be performed using these objective measures of proxemics. In addition, alterations in screen size (Hou et al., 2012; Kim and Kim, 2012) and even mobile screen use (Bababekova et al., 2011; Maniar et al., 2008), should be tested for their effects on proxemics. Such research would, in addition to the findings discussed here, contribute towards an extended framework for understanding the proxemics of screen mediation and the influence of the on-screen subject matter on proxemics (Pederson et al., 2011; Greenberg et al., 2011).

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